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Fatigue Due to Vortex-Induced Crossflow Oscillations in Free Spanning Pipelines Supported on Elastic Soil Bed

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ABSTRACT:

An analytical solution is presented for fatigue response due to crossflow vibration of free spanning submarine pipelines supported on semi-infinite elastic soil bed at the ends. The formulation includes the second order bending effect of axial force present in the pipeline. Free vibration response parameters are obtained by solving the governing differential equations and satisfying the appropriate boundary conditions for both symmetric and anti-symmetric modes. These parameters are used for assessing the fatigue damage due to crossflow vortex induced vibration under wave and current action as per new draft guidelines of DNV. Results are presented illustrating the effect of axial force and soil stiffness on the fatigue life of a free span under a combined wave and current loading scenario. The maximum permissible spans obtained from the full fatigue analysis are compared with those obtained from onset of cross-flow vibration criteria.

KEY WORDS: Cross flow VIV, fatigue analysis, submarine pipeline, free span, analytical solution.

INTRODUCTION

Safety assessment of free spanning submarine pipelines has received distinctly increased attention among the pipeline engineers in the recent years. The effort has been on improving the methodology of assessment so as to accurately predict the risk level of a free span. The aim is to minimise span correction through seabed intervention, which is not only very costly but also dubious and difficult to execute, specially in deep water. A key element in free span assessment is vortex induced vibration (VIV) caused by current and or wave in the suspended pipeline. Till recently, the industry practice in this regard has been to avoid cross-flow VIV by limiting the so called reduced velocity which is a function of water particle velocity, pipe outer diameter and the natural frequency of the span. This VIV onset criteria not only yields conservative results particularly for long spans but also gives no clue to the fatigue risks if the actual reduced velocity exceeds the threshold value. A full fatigue analysis of the pipeline due to cross-flow vibration considering all the stress ranges expected during its design life is required to overcome the above shortcomings. The problem of vortex-induced vibration in submarine pipelines and assessment of its fatigue life has been studied in great detail by several researchers e.g. Celant et. al. (1982), Bruschi et. al. (1982), Tsahalis (1983, 1984), Jacobsen et. al. (1984), Bryndum et. al. (1989). More recently, the focus has been on the development of generalised empirical models, calibrated against test data, that can be implemented in design for predicting flow induced vibration in free spans (Pantazopolous et. al., 1993, Tura et. al., 1994, Mork et. al., 1997). The results of these studies have been encapsulated in a recently issued draft DNV guideline (1997) providing rational methods for fatigue assessment of free spans subjected to combined wave and current loading. An introduction to the DNV guideline can be found in Mork et. al. (1998). The analytical model and hydrodynamic characteristics apart, accuracy of free span fatigue assessment is dependent on the assumptions regarding the boundary conditions, soil-pipe modeling, inclusion or neglect of second order bending effect of axial force present in the pipeline (Fyrleiv et. al., 1998, Kristiansan et. al., 1998). A recent study made by the authors (1998) on the allowable free spans based on the onset of cross-flow VIV criteria has established that the above factors have significant effect on the safe span lengths. It was pointed out that the conventional free span design neglecting the effect of axial force and based on span end conditions idealised as simply supported, fixed or with translational and rotational springs, in many cases, lead to either over-conservative or unsafe estimates. Similar comprehensive study in the case of a full fatigue analysis for crossflow VIV is not yet available in the literature.

Therefore, in this paper, we present a comprehensive analytical formulation to obtain the fatigue response due to cross-flow vibration of a pipeline free-span supported on elastic soil bed at its ends. Second order bending effect due to any axial force that may be present in the pipeline due to pressure, temperature etc. is considered. The solution of the governing differential equation of motion and satisfaction of appropriate boundary conditions for both symmetric and antisymmetric modes yield the characteristic equations for the natural frequencies. These equations are solved numerically using Mathematica (Wolfram, 1991). The mode shape for a given frequency is obtained by computing the unknown constants in terms of an arbitrary factor. The stress due to a maximum modal deflection of one pipe diameter, called as unit stress